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REPORT NO. 17

Project M993

SURFACE FINISH OF TITANIUM AS COMPARED WITH STEEL

by

L. V. COLWELL
R. M. CADDELL

June, 1953

U. S. ARMY, ORDNANCE CORPS
CONTRACT DA-20-018 ORD-11918

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REPORT NO. 17

SURFACE FINISH OF TITANIUM AS COMPARED WITH STEEL

(SHAPING AND TURNING)

By

L. V. COLWELL

R. M. CADDELL

Project M993

U. S. ARMY, ORDNANCE CORPS
CONTRACT NO. DA-20-018-ORD-11918

June, 1953

SUMMARY SHEET

I. Engineering Research Institute, University of Michigan, Ann Arbor, Michigan.

II. U. S. Army, Ordnance Corps.

III. Project No. M993
Contract DA-20-018 ORD-11918, RAD No. ORDTB-1-12045.

IV. Report No. WAL 401/109-17

V. Priority No. - None

VI. Investigation of machinability of titanium-base alloys.

VII. Object:

This investigation was conducted to compare the surface finish of four grades of titanium with that of two standard steels.

VIII. Summary:

One series of tests was performed on a shaper. All conditions were held constant except the feed which was checked at four different rates. Other tests (turning) were made on a lathe. The effects of feed rate and cutting velocity were investigated.

IX. Conclusions:

Since this was a preliminary investigation, the results should be analyzed as indicative of possible trends rather than as conclusive answers. Reduction of feed rate was extremely effective in improving the surface finish. The influence of cutting velocity was found to be dependent upon the range of speeds being considered. In general, the finish produced on titanium was superior to that produced on steel.

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SURFACE FINISH OF TITANIUM AS COMPARED WITH STEEL (SHAPING AND TURNING)

Since improvement of surface finish is an important factor to be considered in metal cutting, these preliminary tests were conducted to investigate the influence of feed and cutting speed on surface finish. In connection with this study an equation was derived which gives the magnitude of the average height of surface roughness as a function of geometry of the cutting tool, the feed rate, and the size and motion of the skids in the profilometer tracer unit. It was assumed that the actual surface finish could not be better (i.e., indicate a lower roughness reading) than the results yielded by this equation. Therefore, the differences existing between the actual readings of surface roughness and theoretical values determined from the equation are indicative of the possible amount of improvement in surface finish. This makes possible a comparison of the finish of titanium and steel, as affected by the feed.

WORK MATERIALS

The materials studied were grade Ti-75A titanium (commercially pure), grade Ti-150A titanium (2.7% Cr and 1.4% Fe), grade RC-130A titanium (7% Mn), grade RC-130B titanium (4% Mn and 4% Al), SAE 1045 hot-rolled steel, and type 304 stainless steel (18% Cr and 8% Ni).

PROCEDURE

A bar of work material was mounted in an engine lathe. Test conditions for feed, speed, and depth of cut were set, and a finished section about one inch long was turned. Successive tests were made until all test conditions were satisfied. This procedure was followed for all work materials.

Similar tests were conducted on a shaper, the work materials being rectangular blocks rather than cylindrical bars.

With the use of a profilometer, readings of surface roughness in microinches were obtained for each test section. The procedure consisted of checking the surface at three different places. Since the profilometer indicator did not yield a single reading of roughness (i.e., the reading might vary from 120-140 microinches during one stroke of the tracer unit), the value judged to be most representative of each trace was selected as the roughness of that particular location. An average of the values obtained at three places on each test section was considered to be representative of the section as a whole. Readings both parallel and perpendicular to the feed marks were determined in this manner for each test section.

Since the data obtained from the variable speed tests using 18-4-1 high-speed-steel tools did not show a definite trend, they were not plotted. However, the roughness readings for these tests are included in Table V. All other data were plotted on cartesian coordinates.

Difficulty was encountered during the shaping tests as the carbide tools tended to chip quickly and severely, usually on the return stroke of the ram. By raising the clapper box clear of the work, this tendency was reduced considerably.

TEST CONDITIONS

Shaping

A 9-inch length of a stroke was used for all tests. Each work specimen was approximately 1 by 2 by 4 inches. For each test, the specimen was held in the table vise and the 2-inch dimension centered with respect to the length of stroke. A depth of cut of 0.025 inch (set to reduce the one inch dimension) and a cutting speed of 27 strokes per minute were used throughout. Feeds of 0.010, 0.020, 0.030, and 0.040 inch per stroke were the rates tested. Solid carbide tool bits, made by the Carboloy Company and marketed as grade 905, were employed. They were 1/2 inch square, 1-1/2 inches long, and had the marking "SQ-16123". By grinding the face of these tools perpendicular to the long axis and holding them in a type SBR-85 tool-holder (made by Wesson Tool Company), the total signature was established. It conformed to the ASA signature -7, -7, 7, 7, 15, 15, 3/64.

A 32-inch Gould and Eberhardt heavy industrial shaper was used. All tests were run without a cutting fluid, and a constant check on the rigidity of the entire setup was carried out.

Turning

Three series of turning tests were conducted. High-speed steel tools of the 18-4-1 composition, marketed as "Blue Chip" by the Firth-Sterling Steel Company, were used for one series. These tools were 1/2 inch square by 4 inches long and conformed to the ASA signature 15, 15, 6, 6, 6, 15, 1/32. The size of cut was fixed at 0.025-inch depth and 0.015-ipr feed. Cutting velocity was varied in five steps from 10 to approximately 100 fpm (top speed being adjusted to suit the material being tested).

For the other two groups of tests, solid carbide tools (Carboloy grade 905) were used which were 1/2 inch square by 1-1/2 inches long. With the tool face ground perpendicular to the long axis, and the tool used in conjunction with a type SBR-85 toolholder (Wesson Tool Company) the tool signature conformed to the ASA shape -7, -7, 7, 7, 15, 15, 3/64. For one series of tests, the depth of cut was fixed at 0.025 inch and the feed rate at 0.015 ipr, while the cutting velocity was assigned values of 50, 100, 200, 300, 400, and 500 fpm. The second series of tests were run with a cutting velocity of 100 fpm and a depth of cut of 0.025 inch while feed rates of 0.005, 0.010, 0.015, and 0.020 ipr were used.

Work materials were in the form of 3-inch-diameter bars, except for the SAE 1045 steel which was in 4-inch-diameter bars. The bars were mounted on a 14-inch-swing American "Pacemaker" lathe with one end held in a four-jaw chuck and the other end against a live center. This lathe was equipped with a Reliance Electric Company "V-S" Drive, making it possible to attain all test speeds, regardless of work diameter. All tests were run without a cutting fluid.

TEST RESULTS

Surface Finish Versus Feed (Shaping)

According to ASME standards, the roughness of a surface is the profilometer reading across the feed marks. This reading should yield the maximum roughness of the surface. A profilometer with a Type J tracer (made by the Micrometrical Manufacturing Company) was used to determine the magnitude of surface roughness. Figure 1 is a summary curve that shows the average values of surface roughness of each work material and the theoretical curve of the "best surface possible". The test curves are representative of actual readings obtained with the profilometer, whereas the theoretical curve is based on an equation which gives the average height of surface roughness as a function of the feed, nose radius and end-cutting-edge angle of the tool, and the radius and motion of the tracer skids. Since the equation and the calculations of theoretical points are extremely lengthy, they have not been included, but it would seem that the derived values are correct, since no actual readings fell below the theoretical curve.

The purpose of obtaining this curve was to get a reasonable indication of the possible amount of improvement in surface finish for each of the work materials. This information can be used to give a relative and an absolute comparison of the finish for these materials. For instance, at a feed of 0.020 ipr, SAE 1045 steel has a roughness of 320 microinches, grade Ti-75A titanium a roughness of 160 microinches, and the "best possible" finish (from the theoretical curve) is 85 microinches. Thus, there is much more improvement possible on SAE 1045 steel than on grade Ti-75A titanium; or, stated otherwise, Ti-75A gives a much better finish than SAE 1045 steel under the same cutting conditions. To facilitate comparisons of the finish on titanium and steel, two tables have been prepared. Table I shows the relative comparisons of the finish of each material at four different feed rates. The values from the theoretical curve were considered as the unit at each selected feed, and the roughness of each material was then expressed as a multiple of this unit. Table II gives a comparison of the absolute values of roughness at the same four feed rates. This indicates the amount of improvement possible in each case.

TABLE I

Feed, ipr	Theor. curve	SAE 1045 steel	304 stainless steel	Ti-75A	Ti-150A	RC-130A	RC-130B
0.010	1	13.0	6.0	4.5	2.8	6.0	4.1
0.020	1	3.7	2.2	1.9	2.2	2.2	1.9
0.030	1	2.0	1.7	1.5	1.5	1.7	1.6
0.040	1	1.38	1.42	1.27	1.16	1.43	1.37

Relative comparison of the surface finish of the test materials, using values from the theoretical curve as the unit at each selected feed rate.

(Shaping)

TABLE II

Feed, ipr	Best surf poss	SAE 1045 steel	304 stainless steel	Ti-75A	Ti-150A	RC-130A	RC-130B
0.010	15	195	90	67	42	90	62
0.020	85	320	185	160	185	190	165
0.030	220	440	370	335	330	380	360
0.040	405	560	575	515	470	580	555

Surface roughness in microinches for all test materials and "best surface possible".

(Shaping)

Tables I and II and Figure 1 show that the actual surface roughness, in microinches, decreases as the feed rate is lowered, regardless of material. It is quite apparent that below a feed of 0.030 ipr, the surface roughness of SAE 1045 steel is considerably greater than that of other material. All grades of titanium are about as good as, if not better than, type 304 stainless steel, below a feed of 0.020 ipr. Table I might be misleading if it is not understood clearly that the base or unit value has a different magnitude at each feed rate. As an illustration, the base value (from the theoretical curve) at a feed of 0.010 ipr is 15 microinches, while SAE 1045 steel shows a roughness of 195 microinches. Thus the actual surface of the steel is 13 times as rough as the theoretical surface. At 0.040 ipr feed, the base value is 405 microinches and the steel has a roughness of 560 microinches, so that the steel is 1.38 times as rough as the theoretical surface. It is incorrect to infer, however, that the actual roughness of the steel is lower at the feed of 0.040 ipr simply because the roughness ratio is lower. The ratios in Table I are intended to provide a rapid comparison of the relative roughness of the materials at any one of the four selected feed rates. Table II was provided to give absolute comparisons of roughness readings at the same four feeds. Ratios in Table I were derived from the values in Table II.

Data points for Figure 1 were obtained from the individual curves in Figures 3 through 8. Roughness readings parallel to the feed marks are also plotted in Figures 3 through 8. Since values such as these are not influenced by the feed marks because the tracer point of the profilometer rides in the valleys between any two adjacent feed marks the readings are always smaller than those obtained across the feed marks. These curves might indicate the influence of the built-up edge on the resulting surface finish. Again, SAE 1045 steel provided higher roughness readings than any other material.

Surface Finish versus Feed (Turning)

Since the results from turning were analyzed in the same way as those from shaping, all introductory explanation of the preceding section pertains here and will not be repeated.

Figure 2 is a summary curve of the roughness readings for each work material, compared with the same theoretical curve used previously (feed only varied to a maximum of 0.020 ipr). Tables III and IV provide relative and absolute comparisons of actual roughness for each material with the roughness of the "best surface possible".

TABLE III

Feed, ipr	Theor. curve	SAE 1045 steel	304 stainless steel	Ti-75A	Ti-150A	RC-130A	RC-130B
0.005	1	70	21	26	11.5	17.5	16
0.010	1	19.3	7	8.7	6.4	7.8	6.7
0.015	1	10	4.9	5.5	4.3	5.4	4.7
0.020	1	7	4.2	4.2	3.4	4.3	3.9

Relative comparison of the surface finish of the test materials, using values from the theoretical curve as the unit at each selected feed rate.

(Turning)

TABLE IV

Feed, ipr	Best surf poss	SAE 1045 steel	304 stainless steel	Ti-75A	Ti-150A	RC-130A	RC-130B
0.005	2	140	42	52	23	35	32
0.010	15	290	105	130	96	117	100
0.015	44	443	215	240	190	238	207
0.020	85	595	360	360	287	370	335

Surface roughness in microinches for all test materials and "best surface possible".

(Turning)

The surface finish for all materials improved as the feed was decreased. SAE 1045 steel was considerably rougher at all feeds, and grade Ti-150A titanium always produced the lowest roughness readings. The finish of all grades of titanium is, in general, at least as good as type 304 stainless steel.

Data points for Figure 2 were obtained from the individual curves in Figures 9 through 14. Roughness readings parallel to the feed marks are plotted on these figures also; SAE 1045 steel was much rougher than any other material. Readings for shaping and turning cannot be compared directly since the cutting velocity differed.

Surface Finish versus Speed

The values of surface roughness produced by the high-speed-steel tools had a large dispersion and lacked any apparent trend. Since the nose radius on the high-speed-steel tools differed from that on the carbide tools, it could not be expected that the results obtained for both types should correlate directly. For similar test conditions, the roughness readings for tests run with HSS tools were almost always higher. It was decided to tabulate the results obtained with HSS tools, and the values of maximum roughness are listed in Table V.

TABLE V

Cutting speed, fpm	SAE 1045 steel	304 Stainless steel	Ti-75A	Ti-150A	RC-130A	RC-130B
10	325	277	205	165	246	265
25	400	320	205	170	205	280
50	428	215	251	210	183	305
65						190
75	510		215	150	165	
80				174	290	
90		200				
100	450		207			

Surface roughness readings in microinches when turning with the 18-4-1 HSS tools at a feed of 0.015 ipr and depth of cut of 0.025 inch.

The blank spaces indicate that the material was not tested at that particular speed. A possible explanation for the erratic dispersion is that the built-up edge was very unstable in this speed region.

Figures 15 through 20 show the data points obtained for turning with carbide tools. Roughness readings parallel with and perpendicular to the feed marks were plotted. The hump on each curve (perpendicular to feed marks) could be explained by the action of the built-up edge. A reduction in the built-up edge produces an improved surface finish. Since an increase in cutting velocity tends to reduce the built-up edge, it is logical to expect an improved surface finish as the velocity is increased. This effect was noted in each case after the highest point of the hump was reached. The hump itself could be due to the unstable action of the built-up edge in that particular speed region, or it could possibly be the result of chatter.

Chipping of the cutting tool could be responsible for the increased roughness in the higher speed regions, where such action did occur. Since this trend seems questionable, a dashed line has been drawn through that portion of the curve (Figures 15, 16, and 18 only).

All grades of titanium produced roughness readings of lower levels than either steel. In the lower speed regions, SAE 1045 steel was considerably rougher than any other material. Although the variations of roughness among all materials decreased considerably in the region of higher speeds, the four grades of titanium were still superior to either steel. Little improvement of finish was found beyond the speed range of 200 to 300 fpm, except for the stainless steel. This material showed constant improvement out to 500 fpm.

CONCLUSIONS

1. Regardless of the work material, a reduction in feed was extremely effective in improving surface finish in both shaping and turning operations. A direct correlation existed between feed and surface finish (i.e.decreasing the feed always improved the finish).

2. Beyond certain speed regions, an increase in cutting velocity improved the surface finish. This usually reached an optimum in the range of 200-300 fpm, and beyond this range, little improvement in finish was noted. In view of the results, however, it is difficult to make a concise recommendation regarding the best speed to be used for each material. It would appear that more extensive testing is needed on this particular phase.

3. For similar cutting conditions, the finishes produced on all grades of titanium were far superior to SAE 1045 steel. In most instances, the finish on all grades of titanium was as good as, if not better than, type 304 stainless steel.

4. The general conclusion is that under similar cutting conditions titanium produces a better finish than steel.

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Surface Finish vs. Feed

(SHAPING)

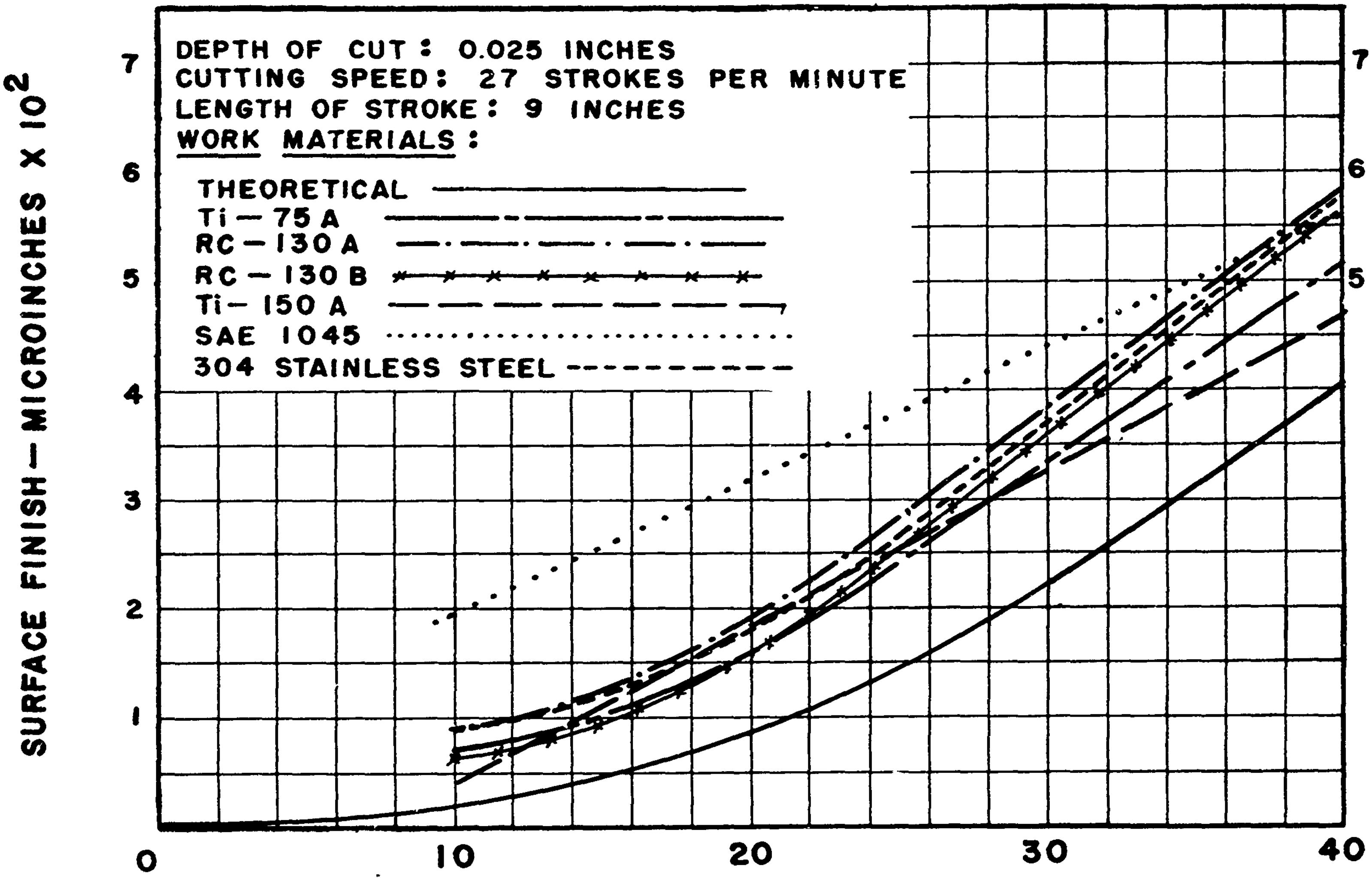


FIG. 1

SURFACE FINISH VS. FEED

(TURNING)

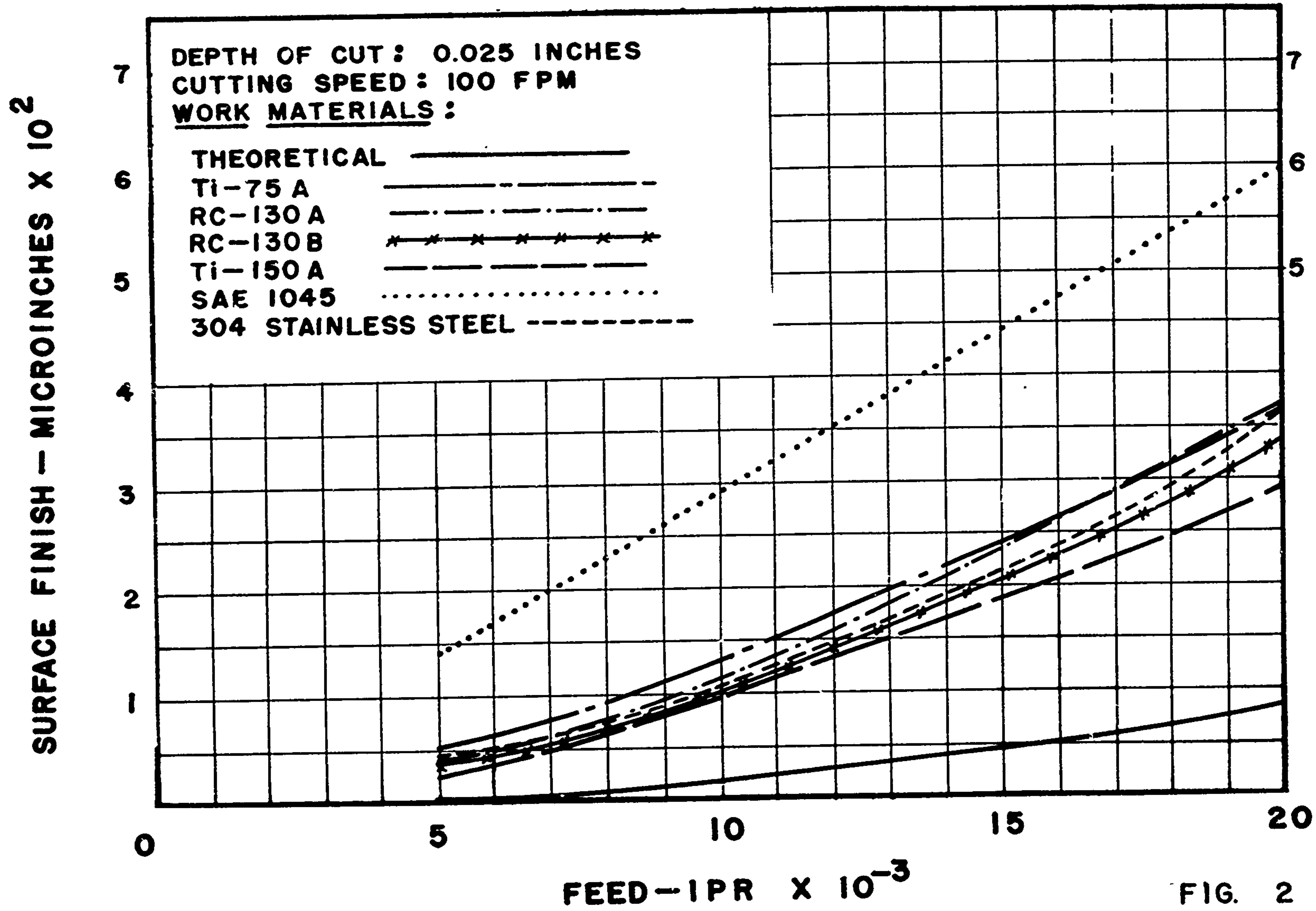


FIG. 2

SURFACE FINISH VS. FEED

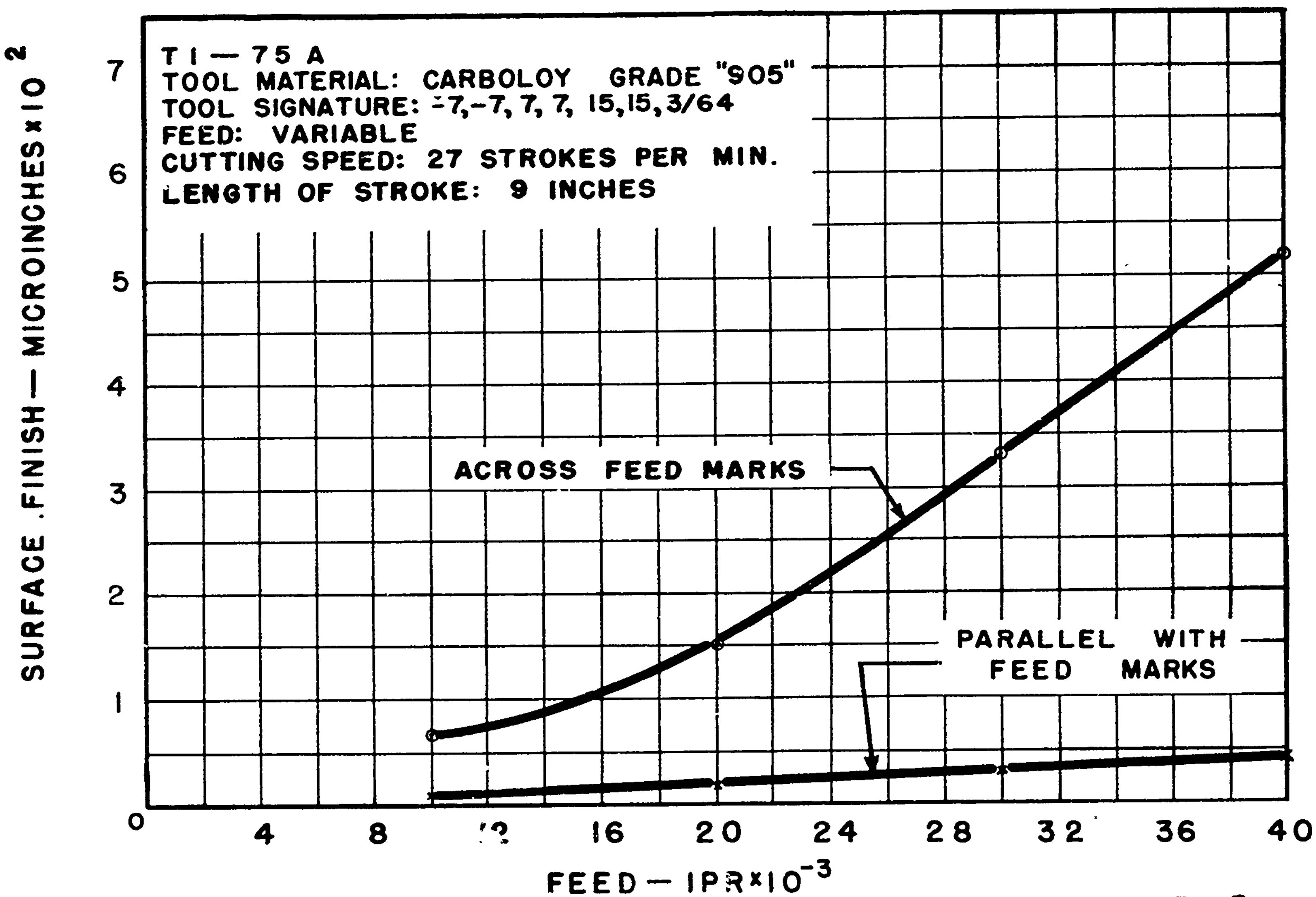


FIG. 3

SURFACE FINISH VS. FEED

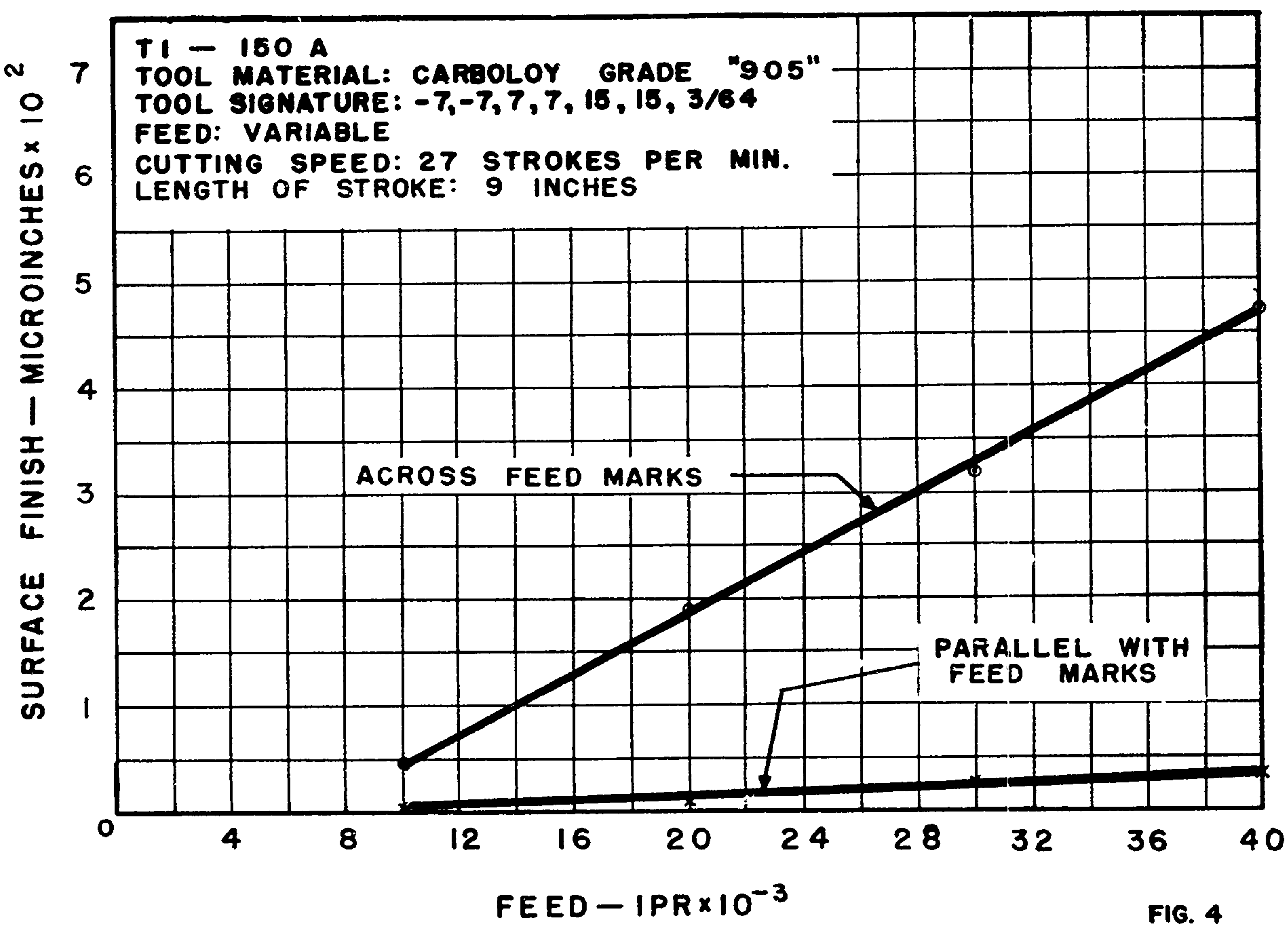


FIG. 4

SURFACE FINISH VS. FEED

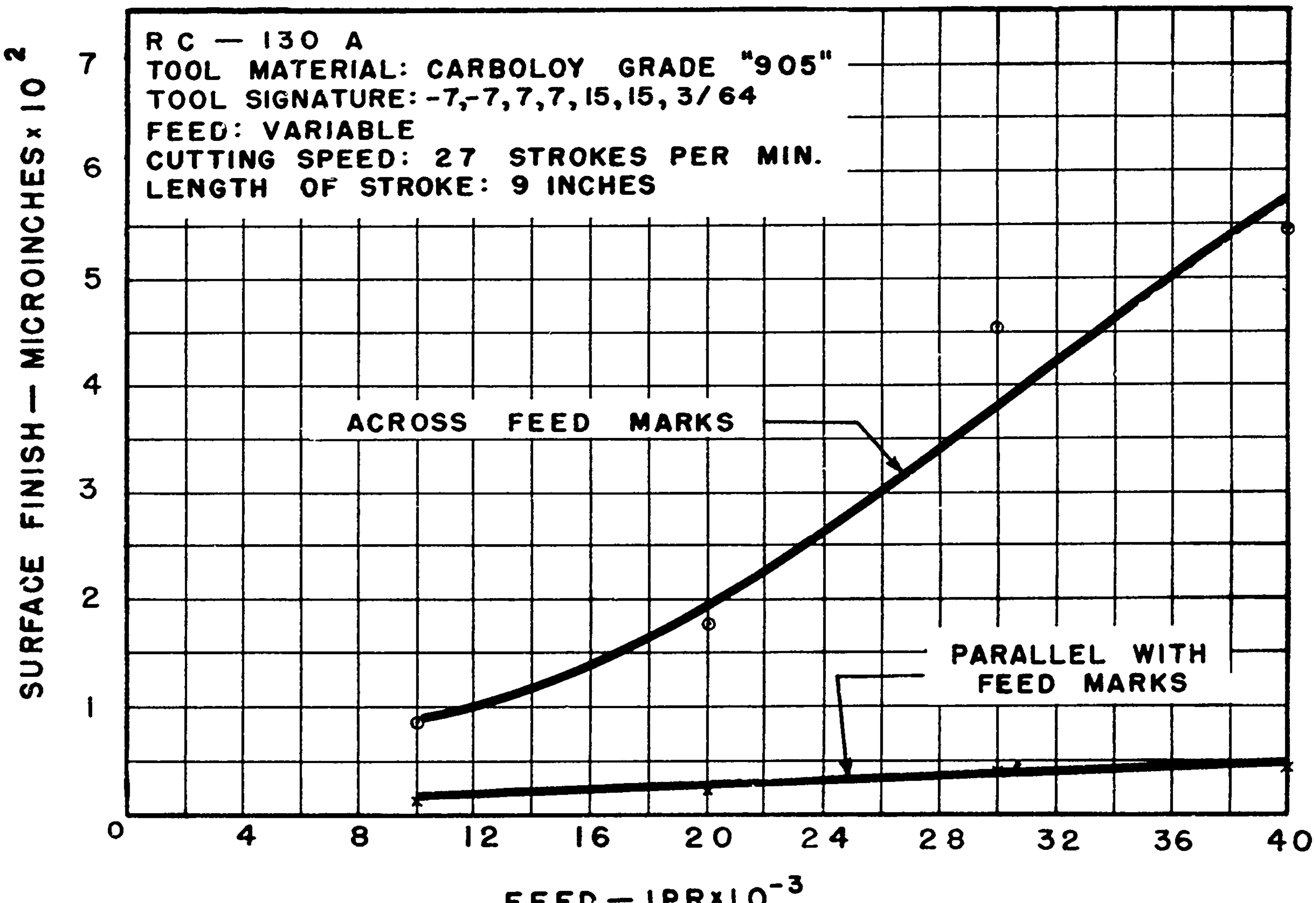


FIG. 5

SURFACE FINISH VS. FEED

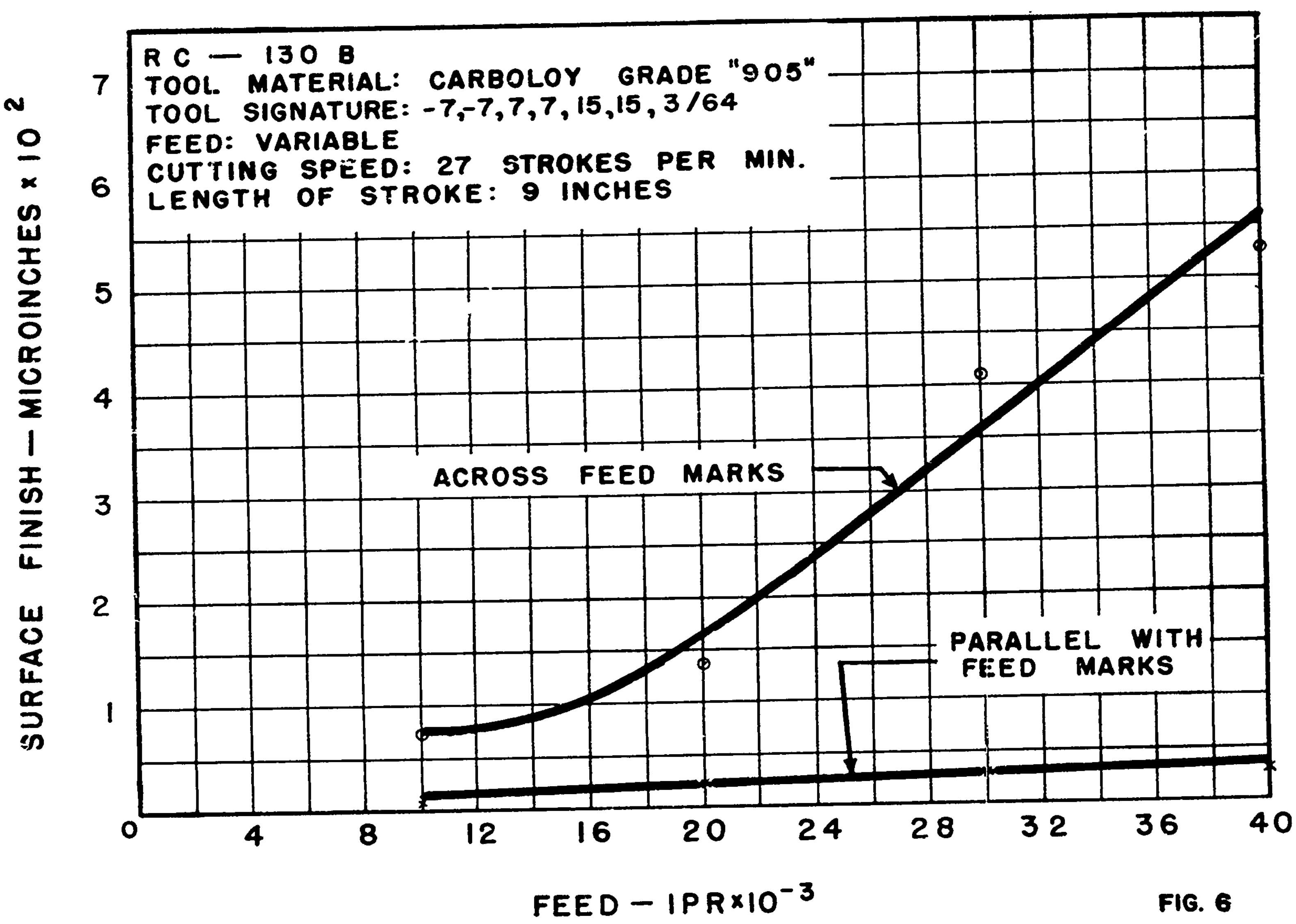


FIG. 6

SURFACE FINISH VS. FEED

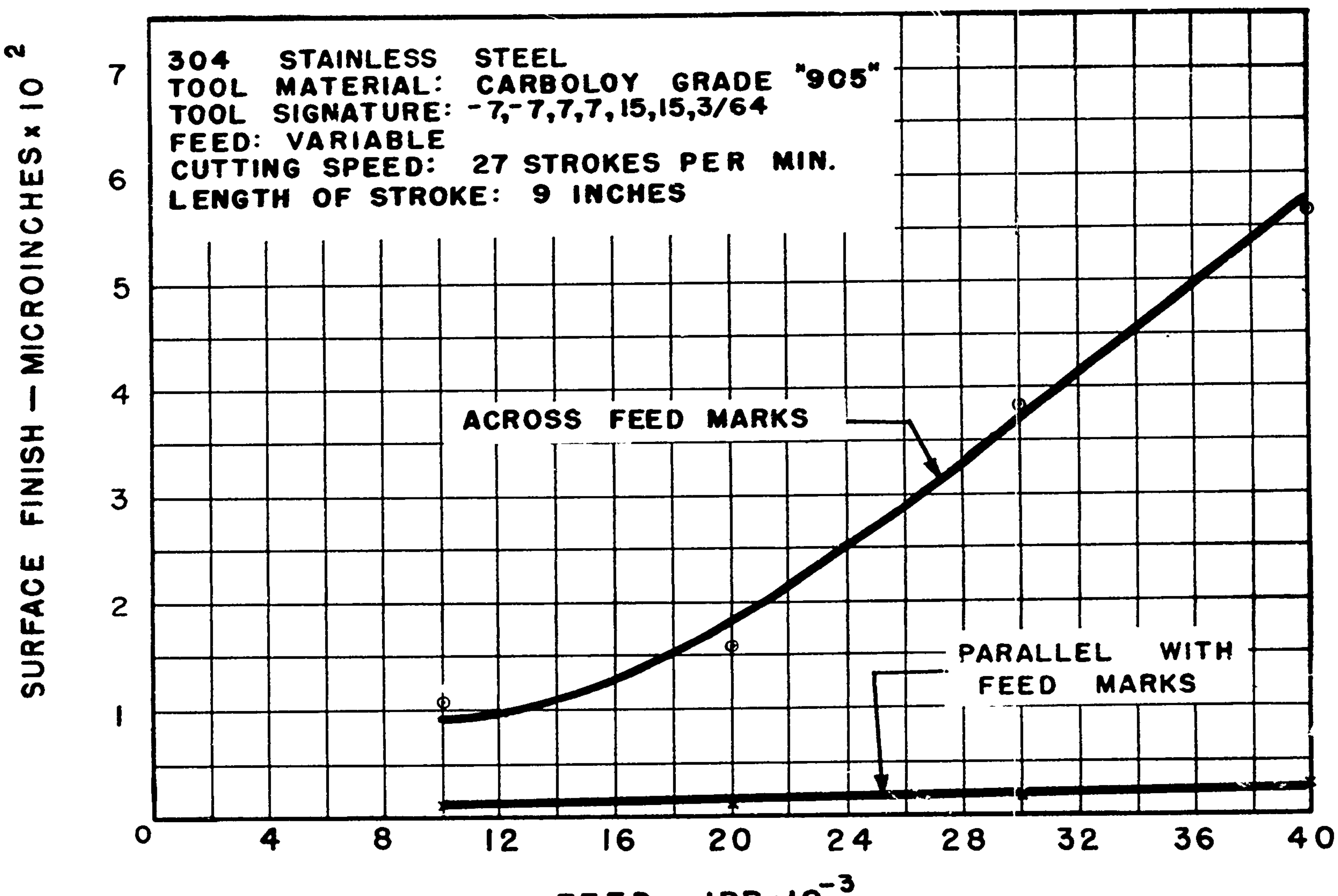


FIG. 7

SURFACE FINISH VS. FEED

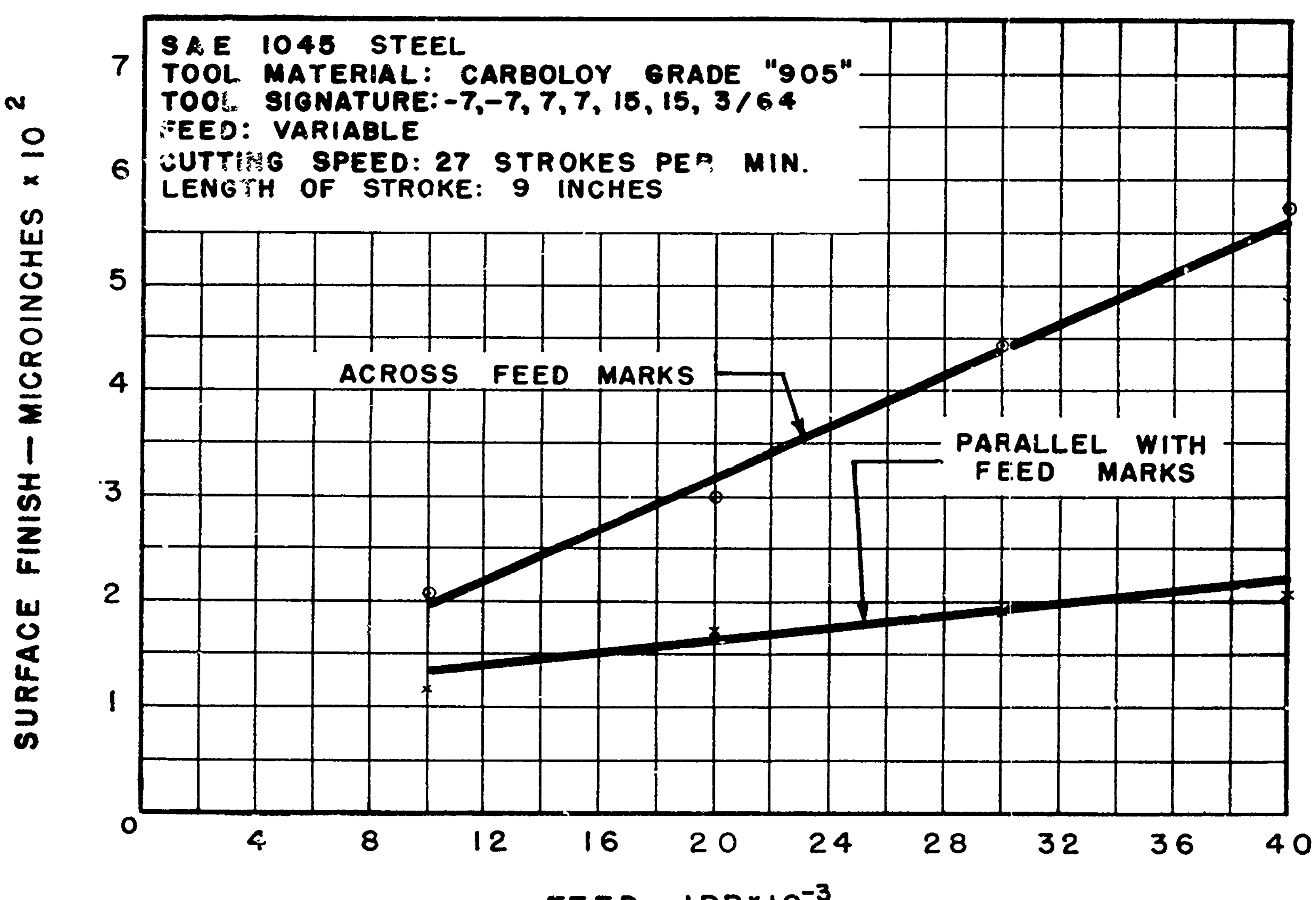


FIG. 8

SURFACE FINISH VS. FEED

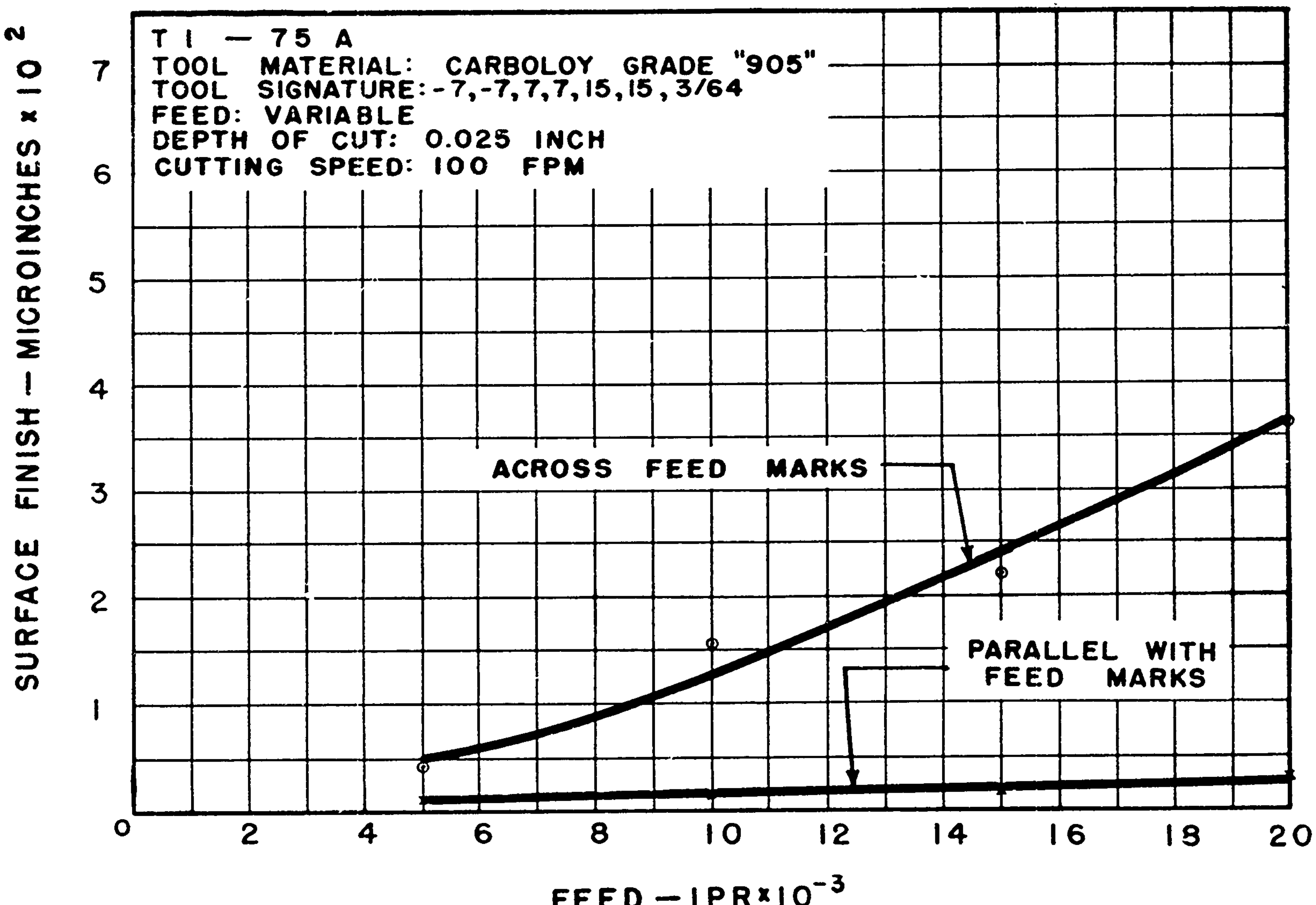


FIG. 9

SURFACE FINISH VS. FEED

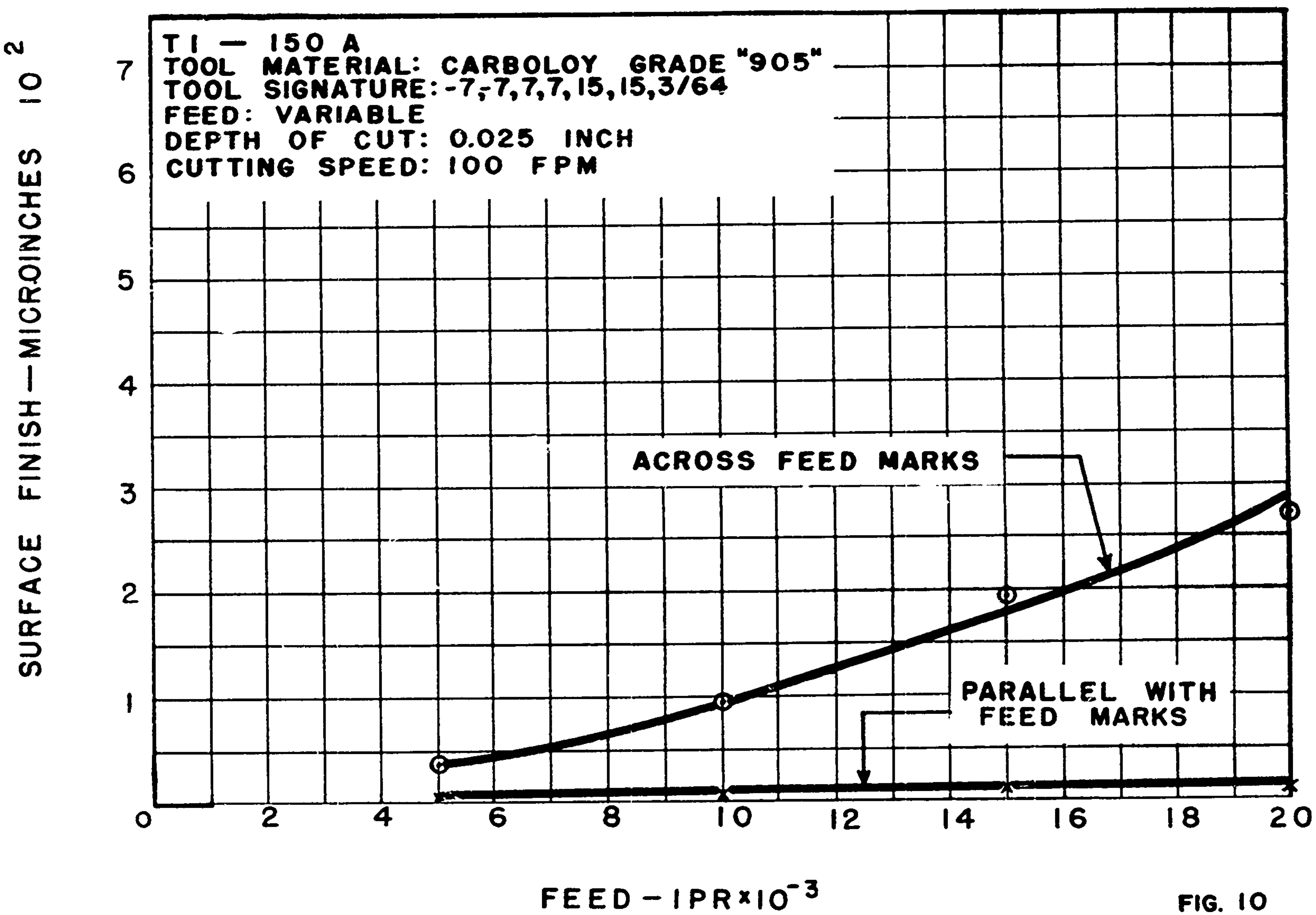


FIG. 10

Surface Finish vs. Feed

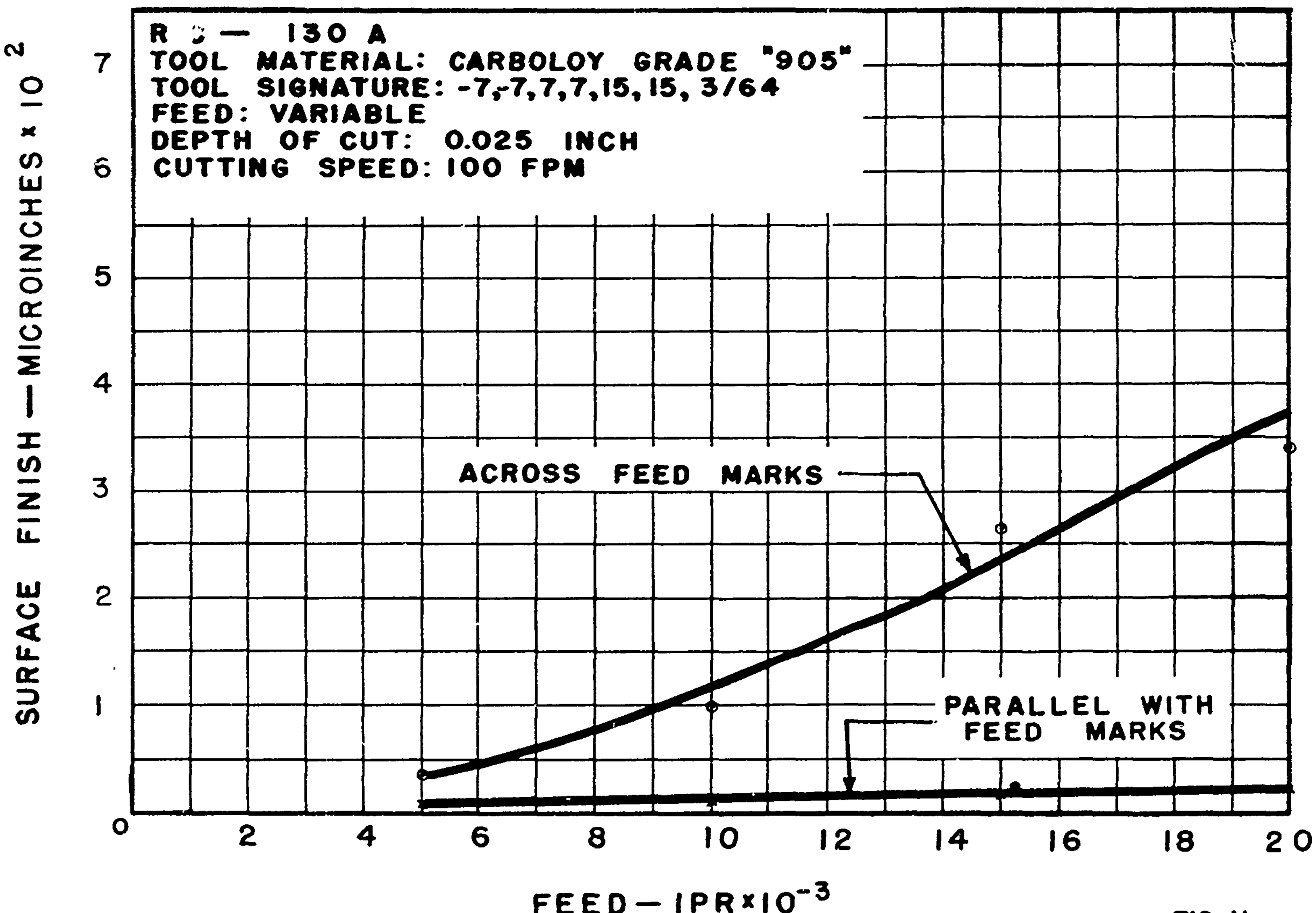
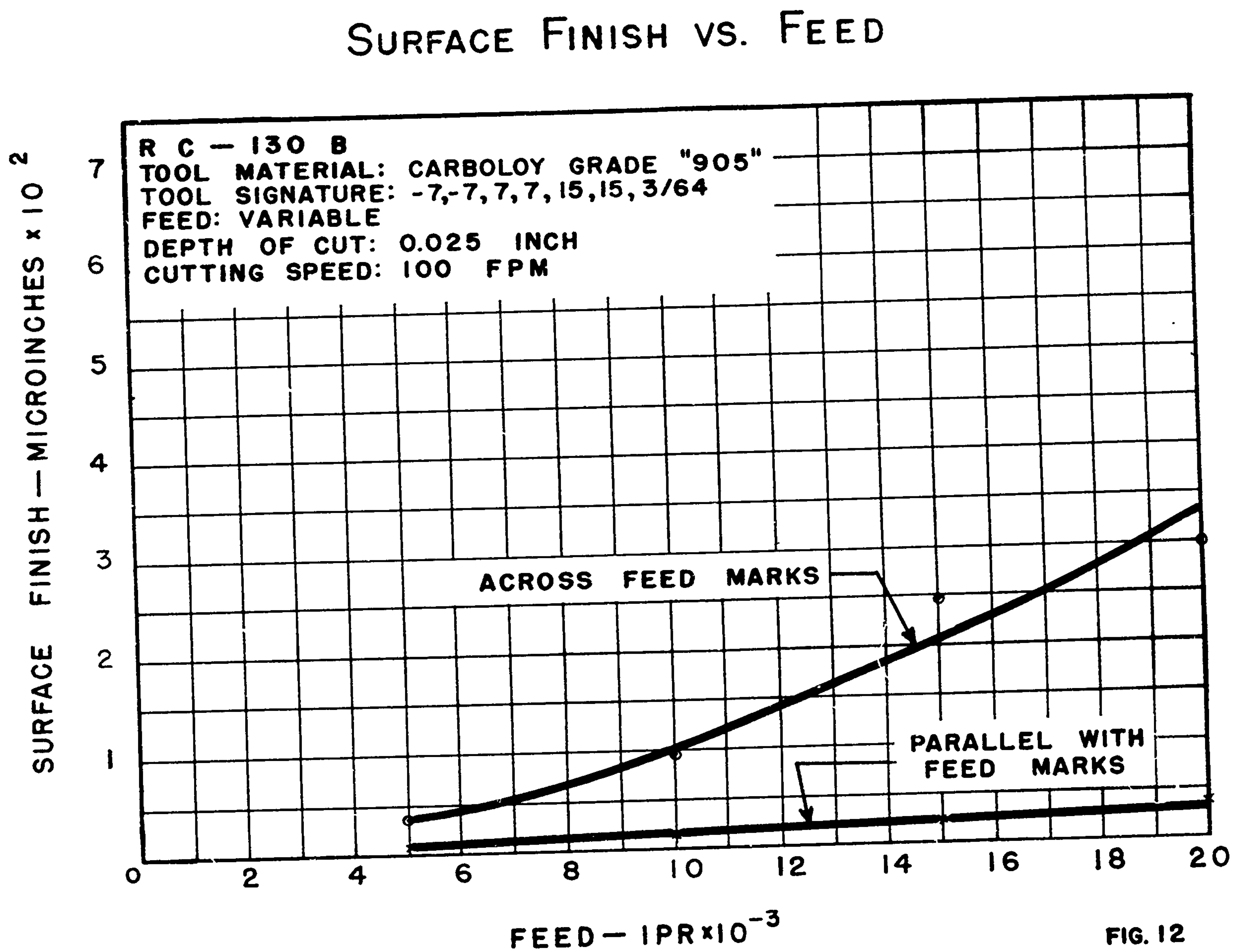


FIG. 11



SURFACE FINISH VS. FEED
R C — 130 B
TOOL MATERIAL: CARBOLOY GRADE "905"
TOOL SIGNATURE: -7,-7,7,7,15,15,3/64
FEED: VARIABLE
DEPTH OF CUT: 0.025 INCH
CUTTING SPEED: 100 FPM
ACROSS FEED MARKS
PARALLEL WITH FEED MARKS
SURFACE FINISH — MICROINCHES x 10 2
1
2
3
4
5
6
7
0
2
4
6
8
10
12
14
16
18
20
FEED — IPR x 10 -3

FIG. 12

SURFACE FINISH VS. FEED

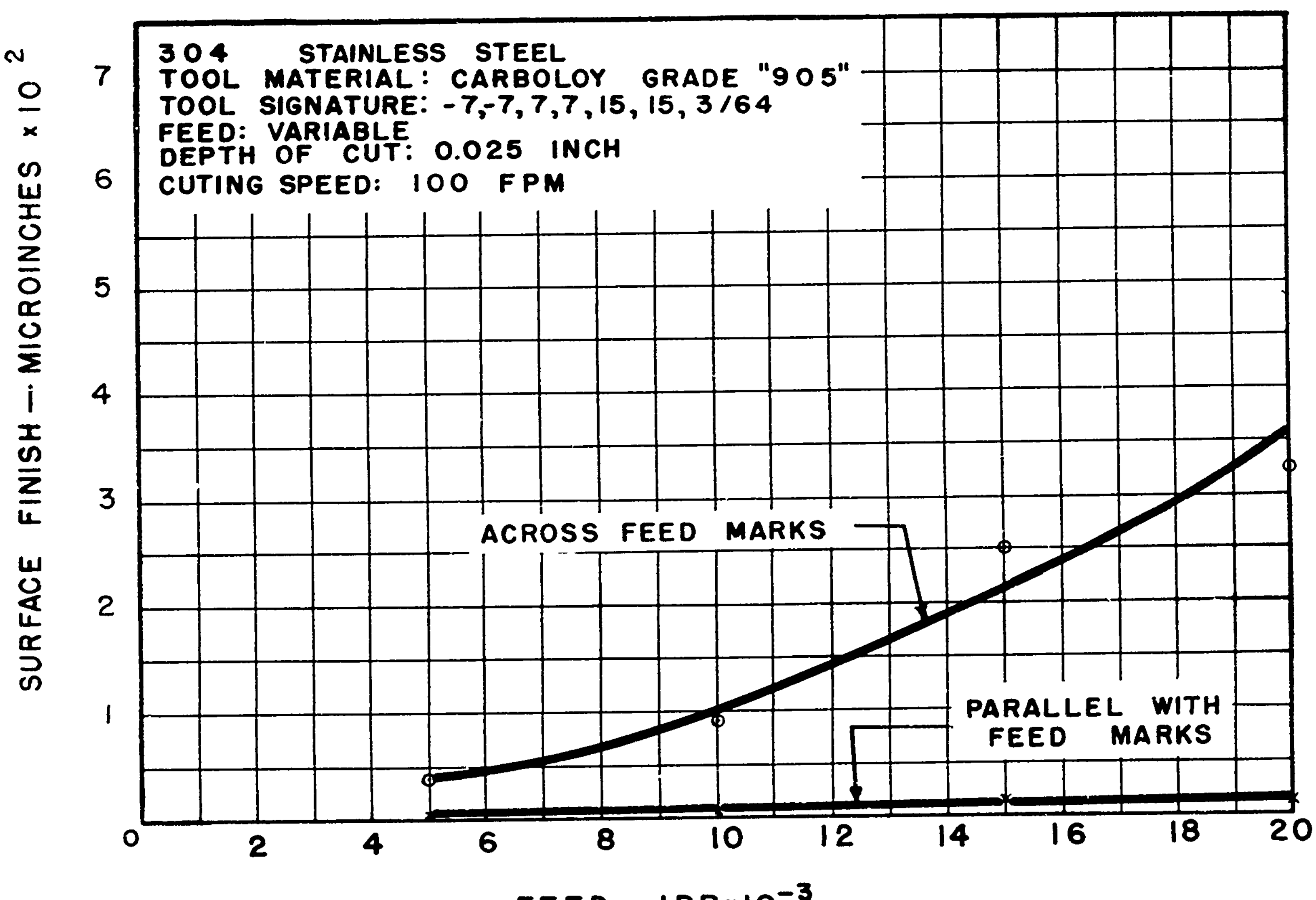


FIG. 13

SURFACE FINISH VS. FEED

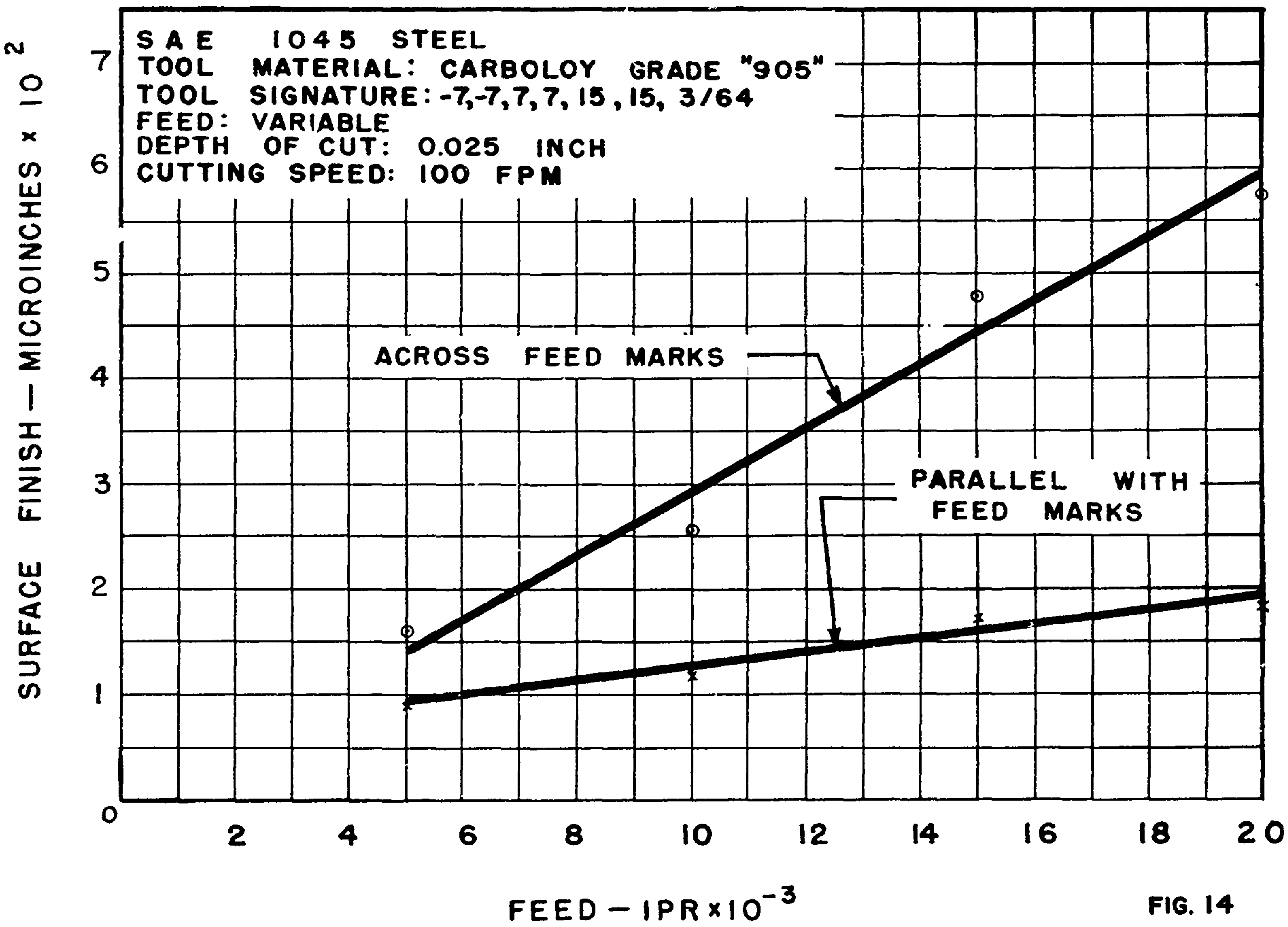


FIG. 14

Surface Finish vs. Cutting Speed

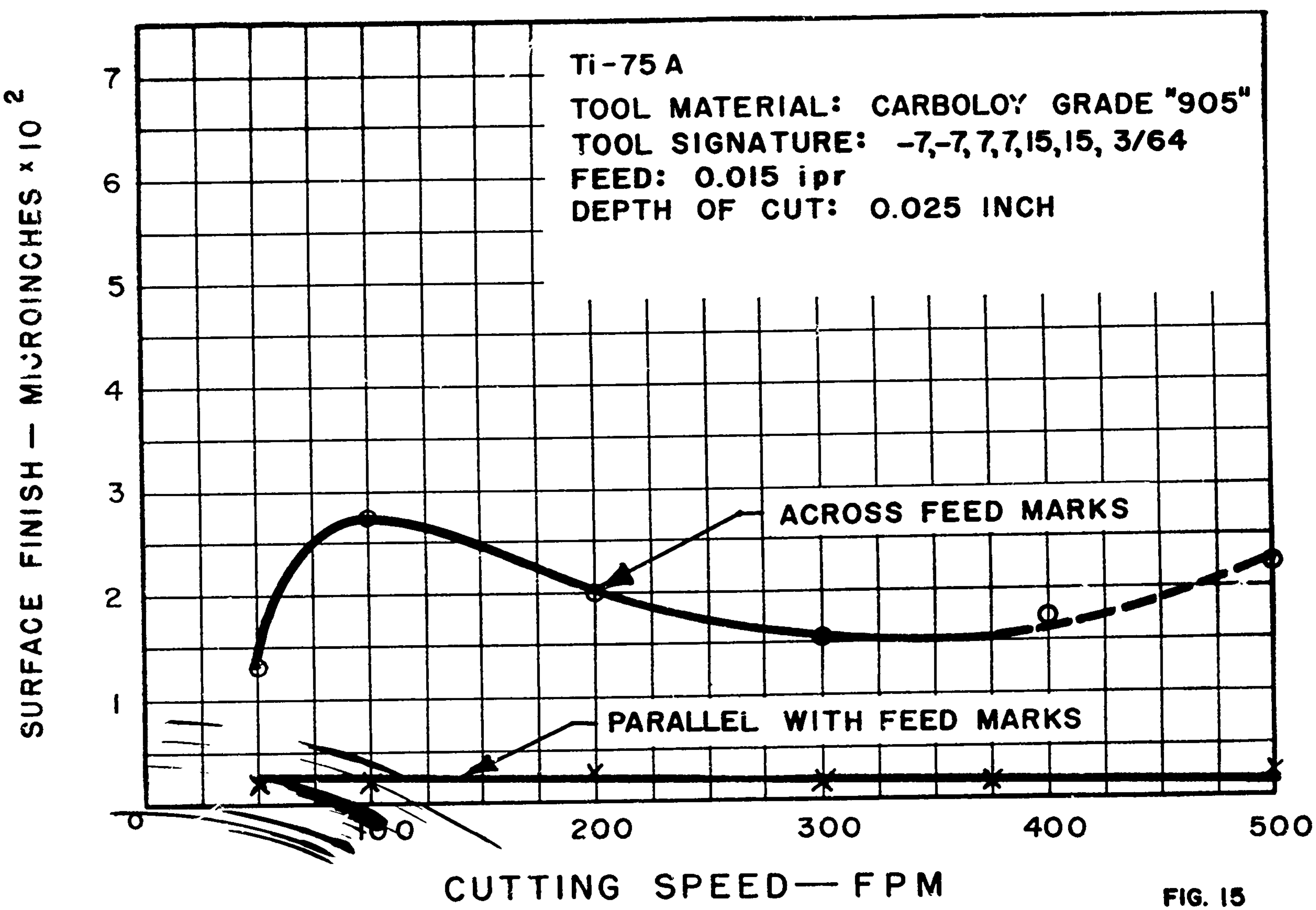


FIG. 15

SURFACE FINISH VS. CUTTING SPEED

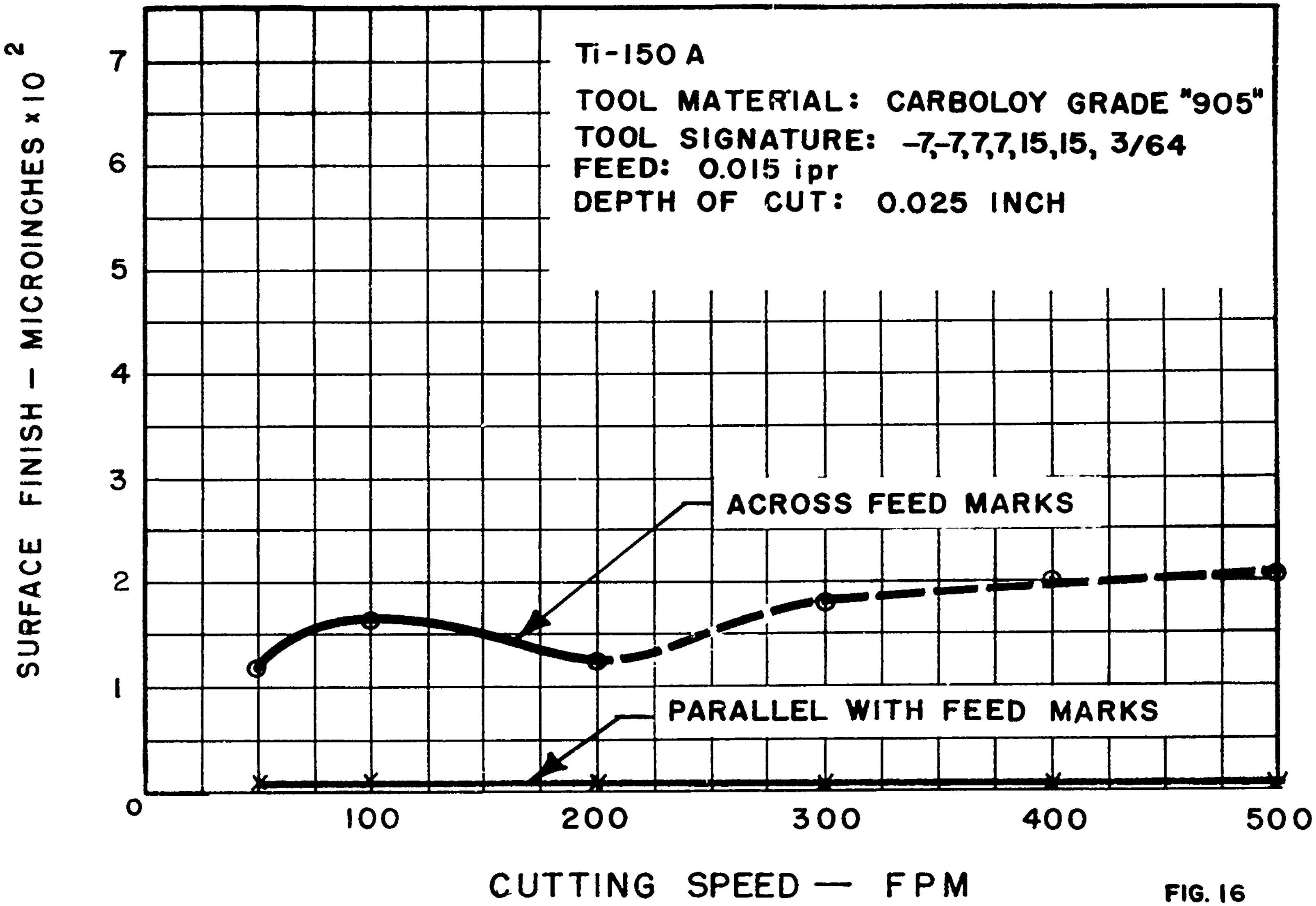


FIG. 16

SURFACE FINISH VS. CUTTING SPEED

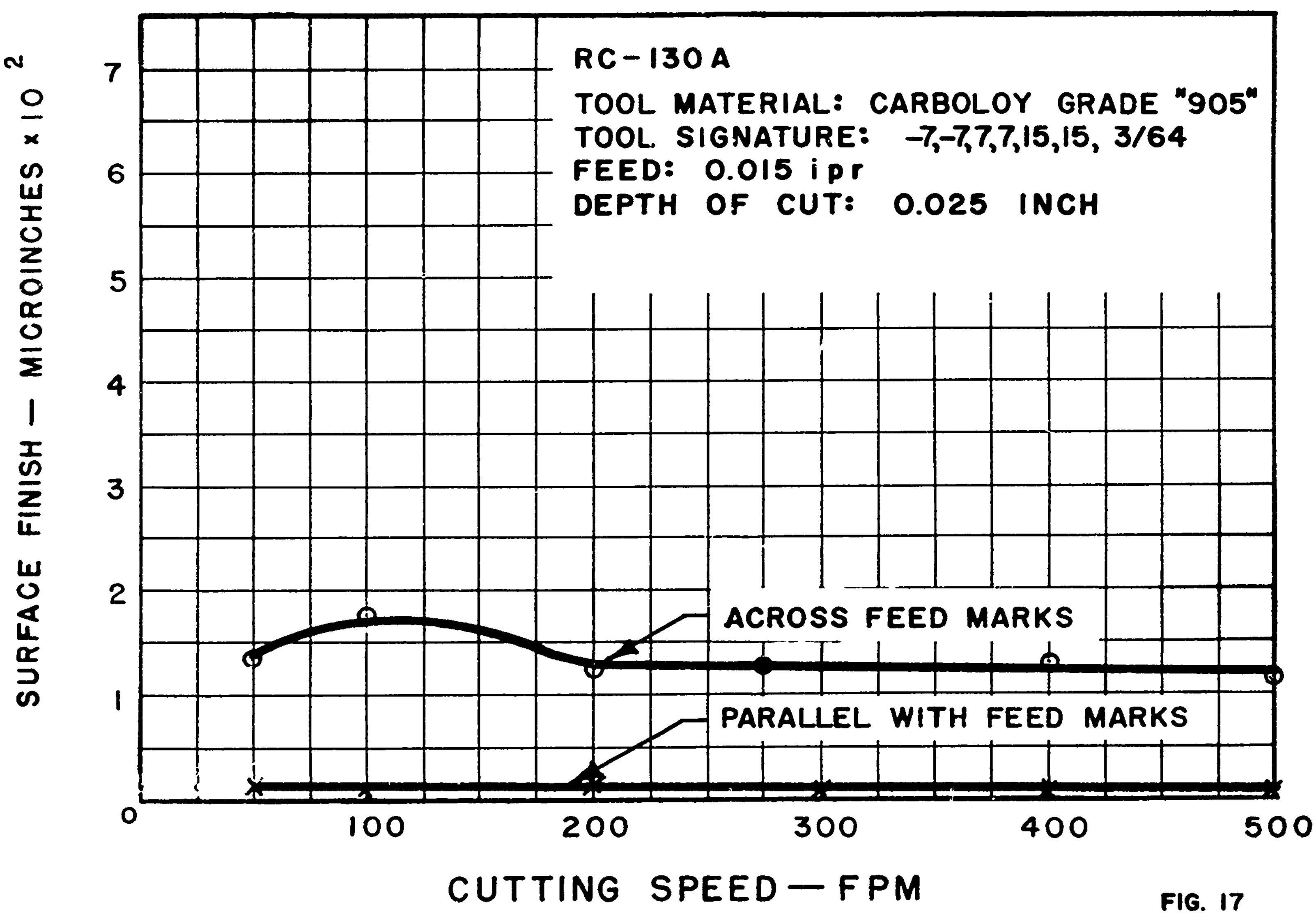


FIG. 17

SURFACE FINISH VS. CUTTING SPEED

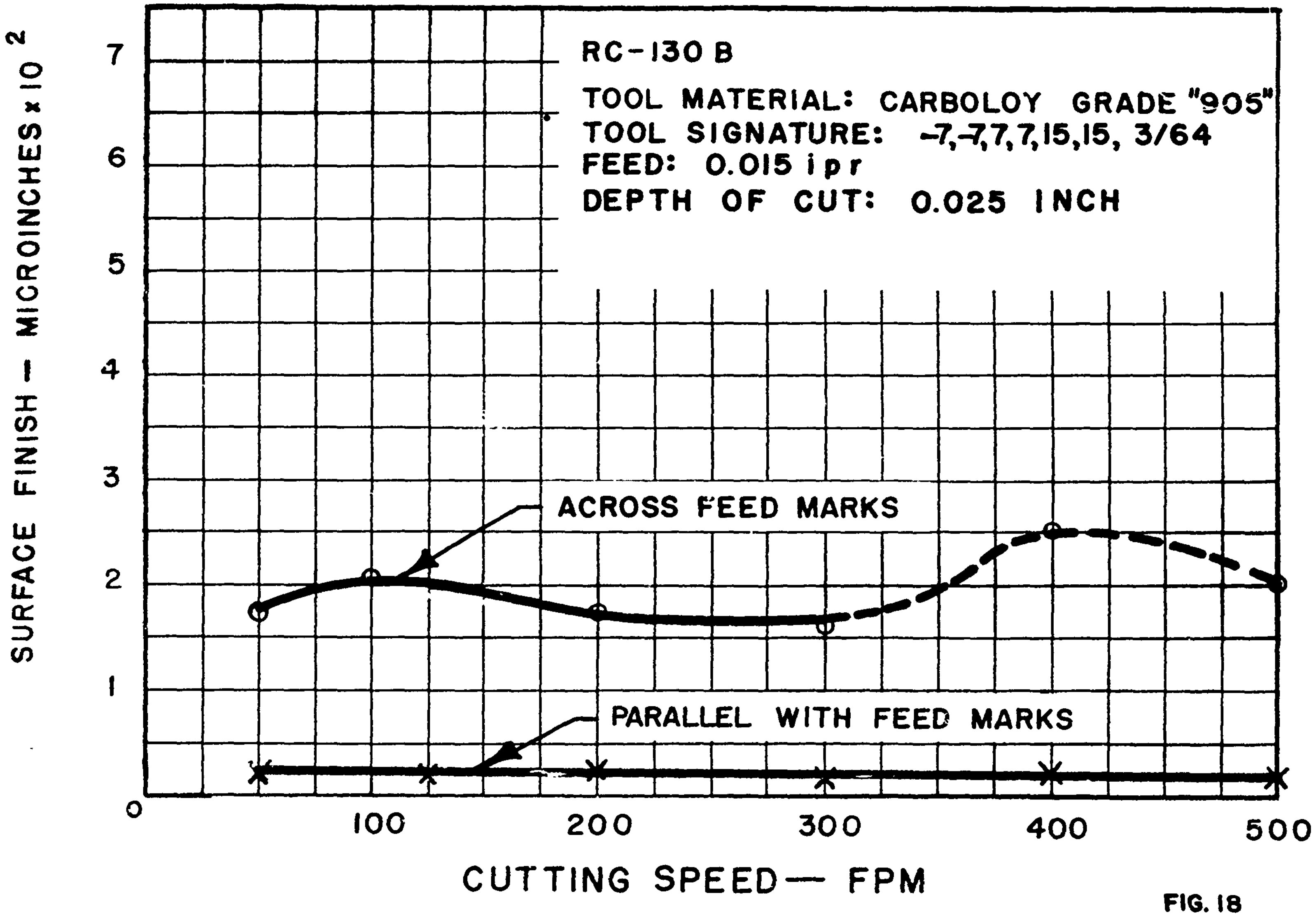


FIG. 18

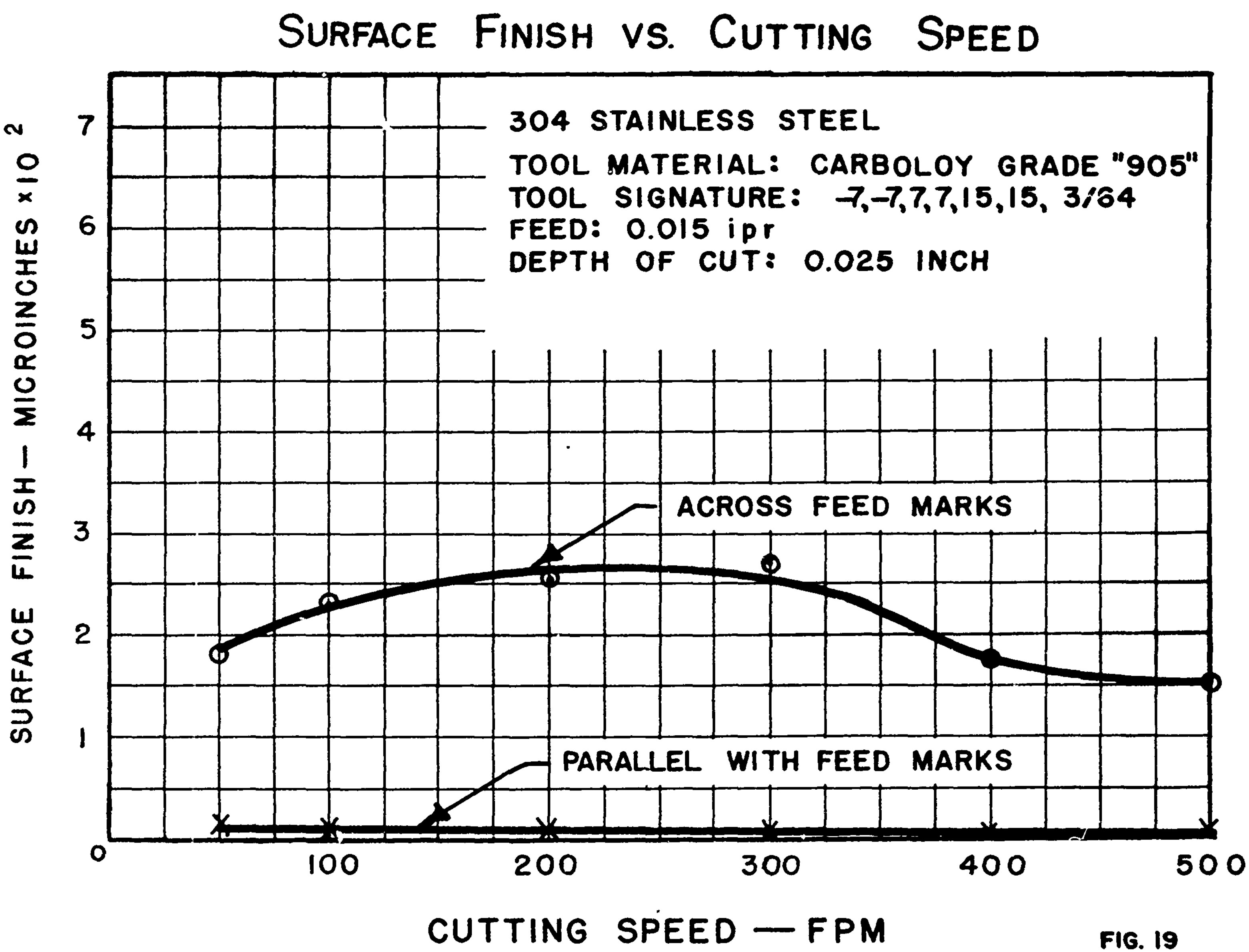

SURFACE FINISH VS. CUTTING SPEED
304 STAINLESS STEEL
TOOL MATERIAL: CARBOLOY GRADE "905"
TOOL SIGNATURE: -7,-7,7,7,15,15, 3/64
FEED: 0.015 ipr
DEPTH OF CUT: 0.025 INCH
ACROSS FEED MARKS
PARALLEL WITH FEED MARKS
SURFACE FINISH — MICROINCHES ×10 2
0
1
2
3
4
5
6
7
100
200
300
400
500
CUTTING SPEED — FPM

FIG. 19

Surface Finish vs. Cutting Speed

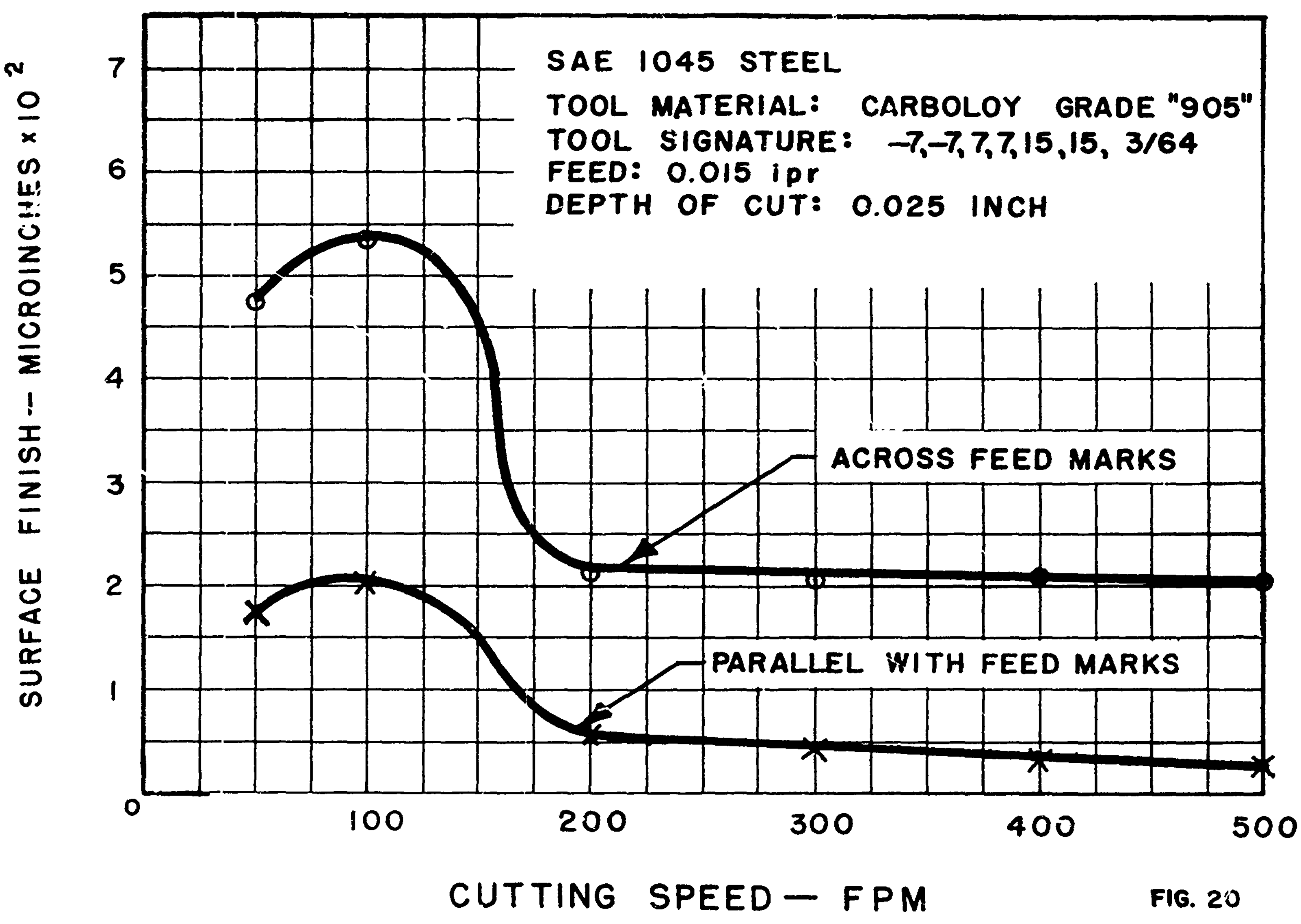


FIG. 20